PERSPECTIVES ON HOW CV AV TECHNOLOGIES AND THE MUTCD

- US DOT – Eric Ferron, FHWA MUTCD Team
- State DOT – Peter Kozinski, Colorado DOT
- Research – Steve Shladover, Berkley
- OEM – Ed Bradley, Toyota
- Technology – Tammy Russell, 3M
- QnA
Connected Vehicles and Traffic Control Devices

Eric Ferron
FHWA Resource Center Operations Technical Service Team
NCUTCD Meeting – January 5, 2017
Agenda

- Fundamental Idea
- Goals
- Key Strategic Challenges
- MUTCD
- Potential Applications

https://www.pcb.its.dot.gov/eprimer/
Fundamental Idea

The power of wireless connectivity to bring about transformative changes in highway safety, mobility, and the environmental impacts of the transportation system.

- Among vehicles (referred to as vehicle-to-vehicle or V2V communications),
- With the infrastructure (vehicle-to-infrastructure or V2I communications), and
- Mobile devices
Goals

- Reduce highway crashes
- Improve mobility
- Enhance transportation system management and operations
- Reduce environmental impacts
Key Strategic Challenges

- To resolve remaining technical, policy, institutional, and funding challenges;
- To conduct testing to determine the actual benefits of applications;
- To determine whether overall benefits are sufficient to warrant implementation, and, if so, how the systems would be implemented; and
- To address issues of public acceptance such as maintaining user privacy and whether systems in vehicles are effective, safe, and easy to use.
MUTCD

- What constitutes a traffic control device?
- Has CV changed the definition of TCDs?
- How do we maintain uniformity?
  - V2V
  - V2I
  - Existing TCD’s
  - New Applications of TCD’s
Potential Applications

- Red Light Running
- Curve Speed Warning
- Stop Sign Gap Assist
- Railroad Crossing Violation
- Spot Weather Warning
- Oversized Vehicle
- Work Zone
Red Light Warning

- Broadcast between an RSE and OBE to determine if the vehicle is in danger of violating a red light
- Warn driver
- Extend all-red phase
Curve Speed Warning

- Uses geometric and weather information
- Determines the appropriate speed
- Warnings can be tailored to the specific vehicle characteristics
Stop Sign Gap Assist

- Uses roadside sensors to detect oncoming traffic
- RSE broadcast traffic status
Railroad Crossing Violation Warning

- Uses roadside equipment to provide a connection to determine the probability of a vehicle conflict
- Issues an alert or warning to the driver
Spot Weather Impact Warning

- Uses a connection from a traffic management center (TMC) and other weather data collection sites
- Issues real-time alert or warning to the driver
Oversize Vehicle Warning

- Uses a connection from an RSE to infrastructure-based detectors
- Either issues an alert to the driver to take an alternate route or provides a warning to stop
Reduced Speed or Work Zone Warning

- Uses an RSE connection to broadcast speed limit and/or work zone information
- Alert the driver to reduce speed, change lanes, or prepare to stop
Questions?
MUTCD Meeting
January 5, 2017
FY 2016-2017
$1.44 Billion Budget

CDOT RESPONSIBILITIES

- Administers $208 million each year in federal grants
- 3,454 bridges
- CDOT maintains & operates 23,000 total lane miles of highway
- 6.1 million miles plowed of snow per year
- 35 mountain passes open year-round
- Division of transit and rail
- Administers Fed/State grants and operates Bustang

Source: Colorado Department of Transportation, 2014
OUR CHALLENGE
Continued Growth

1991
- 3.3 million vehicles
- 27.7 billion vehicle miles traveled
- $125.70 spent per person

2015
- 5.4 million vehicles
- 50.5 billion vehicle miles traveled
- $68.94 spent per person

2040
- 7.8 million vehicles
- 72.3 billion vehicle miles traveled
- $41.16 spent per person

All dollar figures adjusted for inflation.
Transportation Impacts Us All

Vision for the Future

Safety & Reliability

Economic Vitality

Rapid Technological Advancement

Funding
WHY ACCELERATE TECHNOLOGY?

**Safety**
80% of accidents could be reduced or eliminated

**Saved Time**
Could save about 50 minutes per day

**Expanded Mobility**
Mobilizes elderly and handicapped populations

**Innovative Road Solutions**
Could nearly quadruple highway capacity

**Environmental Benefits**
Reduces congestion and vehicle emissions
RoadX VISION: Crash-free, Injury-free, Delay-free and Technologically-transformed travel in Colorado.

RoadX MISSION: Team with public and industry partners to make Colorado one of the most technologically advanced transportation systems in the nation, and a leader in safety and reliability.

Colorado Is Open For Business – Colorado invites partners to join us in accelerating the adoption and deployment of technological solutions.
Colorado partnered with Otto of Uber to complete the world’s first commercial delivery by a self-driving truck. This approximately 120-mile demonstration of self-driving technology in the real-world environment of Colorado is a monumental next step in advancing safety solutions that will help Colorado move towards zero deaths on our roadways. Colorado is enthusiastic about working with Otto and others on:

The long-term impacts and benefits of safely deploying this technology to enhance safety

Improve environmental impacts of highway freight

Foster the economic benefits advanced driving technologies are poised to bring to freight delivery and our state.

TIMING: FALL 2016
NEXT STEPS

People
Educate public

ROI
Invest now in technology platforms

Privacy
Address security issues

Technology & Planning
Plan and model for rapid change

Regulation
Establish consistent policy direction that supports autonomous future
Questions?
Implications of Automation of Road Transport for MUTCD

Steven E. Shladover, Sc.D.
California PATH Program
University of California, Berkeley
NCUTCD Meeting, January 5, 2017
Outline

• Diverse levels of road transport automation, with very different capabilities
• Timing for market introduction and growth
• Diverse technological approaches for automated vehicles acquiring knowledge of road environment
• Implications for infrastructure standards and regulations
Operational Design Domain (ODD)

- The specific conditions under which a given driving automation system ... is designed to function, including, ...
  - Roadway type
  - Traffic conditions and speed range
  - Geographic location (boundaries)
  - Weather and lighting conditions
  - Availability of necessary supporting infrastructure features
  - Condition of pavement markings and signage
  - (and more...)
Driving automation systems are categorized into levels based on:

1. Whether the driving automation system performs either the longitudinal or the lateral vehicle motion control subtask of the dynamic driving task (DDT).
2. Whether the driving automation system performs both the longitudinal and the lateral vehicle motion control subtasks of the DDT simultaneously.
3. Whether the driving automation system also performs object and event detection and response.
4. Whether the driving automation system also performs DDT fallback.
5. Whether the driving automation system is limited by an ODD.
<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Narrative definition</th>
<th>DDT</th>
<th>OEDR</th>
<th>DDT fallback</th>
<th>ODD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DDT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sustained lateral and longitudinal vehicle motion control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>No Driving Automation</td>
<td>The performance by the driver of the entire DDT, even when enhanced by active safety systems.</td>
<td>Driver</td>
<td>Driver</td>
<td>Driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>The sustained and ODD-specific execution by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the driver performs the remainder of the DDT.</td>
<td>Driver and System</td>
<td>Driver</td>
<td>Driver</td>
<td>Limited</td>
</tr>
<tr>
<td>2</td>
<td>Partial Driving Automation</td>
<td>The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the OEDR subtask and supervises the driving automation system.</td>
<td>System</td>
<td>Driver</td>
<td>Driver</td>
<td>Limited</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Driving Automation</td>
<td>The sustained and ODD-specific performance by an ADS of the entire DDT with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately.</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Limited</td>
</tr>
<tr>
<td>4</td>
<td>High Driving Automation</td>
<td>The sustained and ODD-specific performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Limited</td>
</tr>
<tr>
<td>5</td>
<td>Full Driving Automation</td>
<td>The sustained and unconditional (i.e., not ODD-specific) performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Unlimited</td>
</tr>
</tbody>
</table>
# Example Systems at Each Automation Level

<table>
<thead>
<tr>
<th>Level</th>
<th>Example Systems</th>
<th>Driver Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adaptive Cruise Control OR Lane Keeping Assistance</td>
<td>Must drive other function and monitor driving environment</td>
</tr>
<tr>
<td>2</td>
<td>Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist (Mercedes, Tesla, Infiniti, Volvo….) Parking with external supervision</td>
<td>Must monitor driving environment (system nags driver to try to ensure it)</td>
</tr>
<tr>
<td>3</td>
<td>Traffic Jam Pilot</td>
<td>May read a book, text, or web surf, but be prepared to intervene when needed</td>
</tr>
<tr>
<td>4</td>
<td>Highway driving pilot Closed campus “driverless” shuttle “Driverless” valet parking in garage</td>
<td>May sleep, and system can revert to minimum risk condition if needed</td>
</tr>
<tr>
<td>5</td>
<td>Ubiquitous automated taxi Ubiquitous car-share repositioning</td>
<td>No drivers needed</td>
</tr>
</tbody>
</table>
## Personal Estimates of Market Introductions

**based on technological feasibility**

<table>
<thead>
<tr>
<th>Location</th>
<th>Level 1 (ACC)</th>
<th>Level 2 (ACC+ LKA)</th>
<th>Level 3 Conditional Automation</th>
<th>Level 4 High Automation</th>
<th>Level 5 Full Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everywhere</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some urban streets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campus or pedestrian zone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited-access highway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fully Segregated Guideway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Color Key:**

- **Now**
- **~2020s**
- **~2025s**
- **~2030s**
- **~~2075**

- **Personal Estimates of Market Introductions**

- **Based on technological feasibility**
Example Market Growth for Seat Belts After Mandate

Fastest possible adoption, required by law in U.S.

Source: Gargett, Cregan and Cosgrove, Australian Transport Research Forum 2011
Historical Market Growth Curves for Popular Automotive Features

Figure 3.3.10. Diffusion of new technologies in the US car industry (in percent of car output). (Source: Jutila and Jutila, 1986.)
How can a vehicle automation system learn about the road environment?

• Multiple approaches, which can be combined:
  – Digital map database of all relevant road features, combined with vehicle positioning using GPS/INS.
  – 360 degree laser scanner(s) capturing reflections off all surrounding objects and matching them to a detailed database (SLAM)
  – Wireless communication devices on roadside downloading data to vehicles (DSRC, RFID)
  – *Optical sensors capturing visual and IR images of the driving scene and interpreting them*
  – Radar sensors capturing RF reflections off objects in proximity
Implications of optical sensing approach

• Unlikely to be primary because of its vulnerabilities:
  – Loss of visibility in adverse weather (rain, snow, fog, dust,…)
  – Targets obscured by foliage, dirt or snow accumulations
  – Blinding at low sun angles or by glare
  – Confusion by shadows
  – Occlusion by other vehicles
  – Imprecision compared to other methods

• Probably useful to augment data from other methods
Considerations for MUTCD

• No big hurry!
• Anything that improves visibility for human drivers should help automation systems too
  – Human drivers will be the primary road users for many decades to come
  – Good maintenance of existing signs and pavement markings is most important
• Existing sensor systems have widely varying capabilities, but still worse than human eyes
• *** Don’t try to predict “winners” among sensing approaches, especially when technology changes rapidly ***
A Note on Planning Horizons

• Common standards for vehicle optical sensors are unlikely – market competition will produce very diverse products at different price points
• Focus on needs of L1 and L2 driver assistance systems for the foreseeable future
• Remember differences in functional lifetimes of products:
  – Infrastructure: decades
  – Vehicles: years
  – Information technology: months
National Committee Meeting

Tammy Meehan
Global Portfolio Manager
Intelligent Transportation

Jan 5, 2017
3M Intelligent Transportation Materials Video

Automated Vehicles 101

Levels of Automation

The Ecosystem

Highlight: The Vehicle

Ecosystem Engagements Key Themes
Levels of Automation – Automated Vehicles 101

SAE J3016

**LEVEL 0**
No Automation
Human Driver performs all aspects of dynamic driving.

**LEVEL 1**
Driver Assistance
The system controls either steering or speed using information about driving environment. Human driver still performs dynamic driving.

**LEVEL 2**
Partial Automation
The system is in near full control of steering and speed. Human driver must still monitor the environment. Only taking control during specific dynamic driving tasks.

**LEVEL 3**
Conditional Automation
The system does all of the dynamic driving except when it needs the human driver to intervene for specific dynamic driving circumstances (road hazards).

**LEVEL 4**
High Automation
The system is in complete control, but may require the human driver to take control from time to time.

**LEVEL 5**
Full Automation
The system is in full control of all aspects of driving in all conditions.
The Ecosystem

Human

I need to get to my destination safely and efficiently.

I need to enable smarter, safer transportation systems.

3M

Infra-structure

Vehicle

I need to integrate with other systems to avoid collisions and optimize performance.
Automated Vehicle features are comprised of many sensors and systems used to maneuver on the roads.

- **Vehicle Sensors**
  - GPS: Combines readings from tachometers, altimeters, and gyroscopes for accurate positioning. Cost: $500-$6,000
  - Lidar: Monitors the vehicle's surroundings, including the road, other vehicles, and pedestrians. Cost: $200-$3,000
  - Ultrasonic sensors: Measure the position of objects very close to the vehicle. Cost: $15-$20
  - Odometry sensors: Complement and improve GPS information. Cost: $80-$120
  - Video camera: Monitors the vehicle's surroundings and reads traffic lights. Cost (monochrome): $125-$150; Cost (stereo): $150-$300
  - Data connectivity: Provides updates via cellular networks, such as for maps and software. Mostly built-in already today
  - Central ECU: Analyzes all sensor input, applies the rules of the road, and operates steering, the accelerator, and the brakes. Cost: About 50%-200% of sensor costs
  - Radar sensors: Monitor the vehicle's surroundings. Cost (long range): $125-$150; Cost (short range): $50-$100

- **Advanced Driver Assistance Systems**

***Sources***: BCG research and analysis; expert interviews.

© 3M 2017. All Rights Reserved. 3M Confidential.
Key Themes from the Ecosystem

Redundancy and Simplification (Standardization)
Intelligent Transportation Technology and Challenges

Applying science to solve challenges on the road to zero deaths

Technologies
- Vehicle sensors (visual, IR, sonic)
- Automatic braking
- Lane departure warning
- Adaptive cruise control
- Sign recognition

Challenges
- Human behavior/confidence
- Poor/inconsistent road markings
- Technology redundancy
- Inclement weather

Technologies
- Vehicle-to-Vehicle
- Vehicle-to-Infrastructure (beacons)
- Vehicle-to-Cloud
- Big data analytics for traffic mgmt

Challenges
- Intersections, work zones, etc.
- Regulatory standardization
- Connectivity and bandwidth
- Inclement weather
Pavement Markings

“The number 1 issue with the DELPHI Drive across the U.S. was Pavement Marking Detection”

“If you could focus on just one thing it should be making clear and consistent lane markings for the automated vehicle systems”

“We need brighter and greater contrast pavement markings on all roads”

Construction Work Zones

“If you could move the Work Zone Ahead sign up by about 100 meters that could help give us enough notice to allow the driver to take over for Level 4 Automation”

“Work Zones need Connectivity in order to give the vehicles the real time information they’ll need”

“Our most challenging Edge Cases are work zones and specifically how to confidently detect, classify and navigate within the Work zone”
RESEARCH & CV-AV MEETING

• Thursday, 6:00 PM to 7:30 PM
• Adams Room
RESEARCH

• Call to Order and Welcome (Carlson)

• Review problem statements submitted to NCHRP (Carlson)
  • Uniform Guidelines for LED signs
  • Design and Operation of Bicycle Signals
  • Understanding the Physical Highway Infrastructure Needs to Support AV Technologies
  • Signing for Restricted Sight Distance at Vertical Curves
  • Markings for Managed Lanes, Toll Plazas, and Active Travel and Demand Mgmt (ATDM) Operations.

• NCHRP Program Update (Derr)
  • Synthesis Studies Due Date: Feb 17, 2017
  • http://www.trb.org/Studies/Synthesis/SynthesesSubmital.asp

• TRB 2017 AM Preview (Cunard)
CAV TASK FORCE

• Summary of Thursday Panel Presentations

• Technical Committee Input

• Upcoming Events
  • NCUTCD Mtg, Pittsburgh, PA
    • June 28-30, 2017
    • CMU Visit / Demonstrations
  • TRB Automated Vehicle Symposium, San Francisco, CA
    • July 11-13, 2017
    • http://www.automatedvehiclessymposium.org/home